FM-CW RADAR APPARATUS

Applicant claims the right to priority based on Japanese Patent Application No. 2003-12175, filed January 21, 2003.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to an FM-CW radar apparatus that uses a frequency-modulated (FM) continuous wave (CW) as a signal for transmission and, more particularly, to an FM-CW radar apparatus that can detect an overbridge, that is, a stationary object such as a bridge, a road sign, a billboard, or the like, located above the road ahead or on the roadside.

2. Description of the Related Art

A scanning radar scans a given area by turning the radar in lateral directions with very fine step angles within a predetermined time. At each step angle, a radar beam is projected from the radar-equipped vehicle toward a vehicle traveling on the road ahead, and the wave reflected from the vehicle ahead is received; the reflected wave thus received is processed to detect the presence of a vehicle ahead and to compute the distance and relative velocity of that vehicle.

With a conventional radar, however, as the beam is scanned in lateral directions as described above, it is difficult to obtain accurate height information. As a result, when an overbridge, that is, a structure such as a bridge over the road ahead, is detected, it may not be possible to clearly identify whether it is really an overbridge or a vehicle traveling ahead.

In one disclosed method (Japanese Unexamined Patent Publication No. 2002-202365), the detected object is determined as being an overbridge candidate when, of the peak frequencies generated based on the reflected radar signal, the number of frequency peaks larger than a

predetermined value is not smaller than a predetermined number.

There is also disclosed a radar apparatus that radiates a transmitted wave over a prescribed range of angles in the vehicle width direction and in the height direction, and detects angles in the two directions, i.e., the vehicle width direction and the height direction (Japanese Unexamined Patent Publication Nos. 11-38141 and 11-38142).

SUMMARY OF THE INVENTION

It is an object of the present invention to provide an FM-CW radar apparatus that can detect a stationary object, in particular, an overbridge, located above the road ahead in a simple manner.

The FM-CW radar apparatus of the present invention uses a traveling wave antenna as a transmitting antenna, and includes a means for varying in upward/downward directions the projection angle of a combined beam pattern of a transmitted wave radiated from the traveling wave antenna, and an overbridge can be detected by varying the projection angle of the combined beam pattern in the upward direction using the varying means.

The means for varying the projection angle of the combined beam pattern of the transmitted wave in upward/downward directions is a means for varying the frequency of the transmitted wave, and the means for varying the frequency of the transmitted wave varies the frequency by varying a modulating voltage to be input to a voltage-controlled oscillator that outputs the transmit wave. Further, the means for varying the frequency of the transmitted wave includes a means for switching the modulating voltage to be input to the voltage-controlled oscillator that outputs the transmitted wave, and the projection angle of the beam pattern is varied in upward/downward directions by switching the modulating voltage and thereby switching the frequency of the

transmitted wave between an upper band region and a lower band region.

Furthermore, according to the present invention, a phase shifter for varying the projection angle of the beam pattern in upward/downward directions by controlling the phase of the radio wave to be transmitted or received is provided on either a transmitting antenna or a receiving antenna or on a transmitting/receiving antenna, and an overbridge can be detected by controlling the phase shifter and varying the projection angle of the beam pattern in the upward direction.

According to the present invention, as the projection angle of the beam pattern can be varied in the upward direction as described above, an overbridge can be detected without tilting the radar head sensor or the antenna upward and they can be kept stationary.

BRIEF DESCRIPTION OF THE DRAWINGS

The above object and features of the present invention will be more apparent from the following description of the preferred embodiments with reference to the accompanying drawings, wherein:

Figs. 1A, 1B, and 1C are diagrams for explaining the principle of FM-CW radar when the relative velocity with respect to target is 0;

Figs. 2A, 2B, and 2C are diagrams for explaining the principle of FM-CW radar when the relative velocity with respect to target is v;

Fig. 3 is a diagram showing one configuration example of a two-antenna FM-CW radar;

Fig. 4 is a diagram showing one configuration example of a single-antenna FM-CW radar;

Figs. 5A and 5B are diagrams showing a prior art method for detecting an overbridge by radar;

Fig. 6 is a diagram showing another prior art method for detecting an overbridge by radar;

Fig. 7 is a diagram showing a method for forming a

radar beam pattern according to the present invention;

Fig. 8 is a diagram showing the configuration of a traveling wave antenna used in the present invention;

Fig. 9 is a diagram depicting the antenna shown in Fig. 8 when mounted on a radar apparatus;

Figs. 10A, 10B, and 10C are diagrams showing the relationship between the modulating voltage Vmod output from a modulating signal generator (MOD) 1 and the frequency f of the frequency-modulated wave output from a voltage-controlled oscillator (VCO) 2 in Figs. 3 and 4;

Figs. 11A and 11B are diagrams showing the relationship between the frequency f of the frequency-modulated wave and tilt angle θ;

Fig. 12 is a diagram showing an embodiment of a radar apparatus according to the present invention; and

Fig. 13 is a diagram showing an embodiment of a radar apparatus according to the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Before describing the radar apparatus of the present invention, the principle of an FM-CW radar will be described.

An FM-CW radar measures the distance to a target object, such as a vehicle traveling ahead, by transmitting a continuous wave frequency-modulated, for example, in a triangular pattern. More specifically, the transmitted wave from the radar is reflected by the vehicle ahead, and the reflected signal is received and mixed with the transmitted signal to produce a beat signal (radar signal). This beat signal is fast Fourier transformed to analyze the frequency. The frequency-analyzed beat signal exhibits a peak at which power becomes large in correspondence with the target. The frequency corresponding to this peak is called the peak frequency. The peak frequency carries information about distance, and the peak frequency differs between the rising portion and falling portion of the triangular FM-

CW wave due to the Doppler effect associated with the relative velocity with respect to the vehicle ahead. The distance and relative velocity with respect to the vehicle ahead are obtained from the peak frequencies in the rising and falling portions. If there is more than one vehicle traveling ahead, a pair of peak frequencies in the rising and falling portions is generated for each vehicle. Forming pairs of peak frequencies in the rising and falling portions is called pairing.

Figs. 1A, 1B, and 1C are diagrams for explaining the principle of the FM-CW radar when the relative velocity with respect to the target is 0. The transmitted wave is a triangular wave whose frequency changes as shown by a solid line in Fig. 1A. In the figure, $f0$ is the center frequency of the transmitted wave, Δf is the FM modulation width, and Tm is the repetition period. The transmitted wave is reflected from the target and received by an antenna; the received wave is shown by a dashed line in Fig. 1A. The round trip time T to and from the target is given by $T = 2r/C$, where r is the distance (range) to the target and C is the velocity of radio wave propagation.

Here, the received wave is shifted in frequency from the transmitted signal (i.e., produces a beat) according to the distance between the radar and the target.

Fig. 1B is a diagram showing the beat frequency, and Fig. 1C is a diagram showing the beat signal.

The frequency component fb of the beat signal can be expressed by the following equation.

$$fb = fr = (4 \cdot \Delta f / C \cdot Tm) r$$

where fr is the frequency due to the range (distance).

Figs. 2A, 2B, and 2C, on the other hand, are diagrams for explaining the principle of the FM-CW radar when the relative velocity with respect to the target is v. The frequency of the transmitted wave changes as shown by a solid line in Fig. 2A. The transmitted wave

is reflected from the target and received by the antenna; the received wave is shown by a dashed line in Fig. 2A.

Here, the received wave is shifted in frequency from the transmitted signal (i.e., produces a beat) according to the distance between the radar and the target.

Fig. 2B is a diagram showing the beat frequency, and Fig. 2C is a diagram showing the beat signal.

In this case, as the relative velocity with respect to the target is v, a Doppler shift occurs, and the beat frequency component fb can be expressed by the following equation.

$$fb = fr \pm fd = (4 \cdot \Delta f / C \cdot Tm) r \pm (2 \cdot f0 / C) v$$

where fr is the frequency due to the distance, and fd is the frequency due to the velocity.

The symbols in the above equation have the following meanings.

fb: Transmit beat frequency

fr: Range (distance) frequency

fd: Velocity frequency

f0: Center frequency of transmitted wave

Δf: Frequency modulation width

Tm: Period of modulation wave

C: Velocity of light (velocity of radio wave)

T: Round trip time of radio wave to and from target object

r: Range (distance) to target object

v: Relative velocity with respect to target object

Fig. 3 is a diagram showing one configuration example of a two-antenna FM-CW radar. As shown, a modulating signal generator (MOD) 1 applies a modulating signal to a voltage-controlled oscillator (VCO) 2 for frequency modulation, and the frequency-modulated wave is passed through a directional coupler 3 and transmitted out from a transmitting antenna (AT), while a portion of the transmitted signal is separated by the directional coupler 3 and fed into a mixer 4. The signal reflected

from the target is received by a receiving antenna (AR), and the received signal is mixed in the mixer 4 with the output signal of the voltage-controlled oscillator (VCO) 2 to produce a beat signal. The beat signal is passed through a filter (F) 5, and is converted by an A/D converter (A/D) 6 into a digital signal; the digital signal is then supplied to a digital signal processor (DSP) 7 where signal processing, such as a fast Fourier transform, is applied to the digital signal to obtain the distance and the relative velocity.

Fig. 4 is a diagram showing one configuration example of a single-antenna FM-CW radar. As shown, a modulating signal generator (MOD) 1 applies a modulating signal to a voltage-controlled oscillator (VCO) 2 for frequency modulation, and the frequency-modulated wave is passed through a directional coupler 3 and transmitted out from a transmitting/receiving antenna (ATR), while a portion of the transmitted signal is separated by the directional coupler 3 and fed into a first mixer 4-1. The signal reflected from the target is received by the transmitting/receiving antenna (ART). SW8 is a transmit-receive switch which switches the antenna between transmission and reception by a signal fed from a transmit-receive switching signal generator (OSC) 9 constructed from an oscillator. The received signal is mixed in the first mixer 4-1 with the output signal of the voltage-controlled oscillator (VCO) 2 to produce an IF signal. The IF signal is mixed in a second mixer 4-2 with the signal from the OSC 9, and is thus downconverted, producing a beat signal. The beat signal is passed through a filter (F) 5, and is converted by an A/D converter (A/D) 6 into a digital signal; the digital signal is then supplied to a digital signal processor (DSP) 7 where signal processing such as a fast Fourier transform is applied to the digital signal to obtain the distance and the relative velocity.

Figs. 5A and 5B are diagrams showing a prior art

method for detecting an overbridge by radar. Fig. 5A shows the normal beam pattern (BP) of the radar beam, the beam pattern being formed in the horizontal direction from a radar sensor head (RSH). Fig. 5B shows the case in which the RSH is tilted upward; in this case, the beam pattern is formed directed obliquely upward, and an overbridge can thus be detected.

Fig. 6 is a diagram showing another prior art method for detecting an overbridge by radar. According to this method, rather than tilting the radar sensor head (RSH) upward, the antenna is tilted upward to project the beam pattern obliquely upward, as shown in Figure 6, to detect an overbridge.

Embodiment 1

Fig. 7 is a diagram showing a method for forming a radar beam pattern according to the radar apparatus of the present invention. As shown, according to the radar apparatus of the present invention, the beam pattern can be formed directed obliquely upward without tilting the radar sensor head or the antenna. In the present invention, the projection angle of the beam pattern can be varied not only in the upward direction but also in the downward direction.

Fig. 8 is a diagram showing the configuration of a traveling wave antenna used in the present invention. According to the radar apparatus of the present invention, when this antenna is used as the transmitting antenna of the FM-CW radar apparatus shown in Fig. 3 or 4, for example, the projection angle of the radar beam pattern can be varied in upward/downward directions by varying the tilt angle θ of the combined beam pattern (BP) radiated from the antenna, without varying the mounting angle of the radar sensor head or the angle of the antenna.

In the case of the antenna shown in Fig. 8, there are three feedpoints, and the physical optical path

difference is designated by L. The tilt angle θ of the combined beam pattern varies with the electrical phase. When the wavelength of the transmit wave to be transmitted out from the antenna is denoted by λg, the electrical phase is given by $L/\lambda g$, which means that the tilt angle θ can be varied by varying the wavelength of the transmit wave, that is, the frequency of the transmitted wave.

Fig. 9 is a diagram depicting the antenna shown in Fig. 8 when mounted on the radar apparatus. As shown in Fig. 9, the angle of the combined beam pattern radiated from the antenna can be varied in upward/downward directions by varying the tilt angle θ.

As noted above, the tilt angle θ can be varied by varying the frequency of the transmitted wave. Figs. 10A, 10B, and 10C are diagrams showing the relationship between the modulating voltage Vmod output from the modulating signal generator (MOD) 1 and the frequency f of the frequency-modulated wave output from the voltage-controlled oscillator (VCO) 2 in Figs. 3 and 4. As shown in Fig. 10A, when the modulating voltage Vmod of the MOD 1 is a relatively low voltage V1, the frequency f of the frequency-modulated wave output from the VCO 2 is also low.

On the other hand, as shown in Fig. 10B, when the modulating voltage Vmod of the MOD 1 is a relatively high voltage V2, the frequency f of the frequency-modulated wave output from the VCO 2 is also high.

Fig. 10C shows the above relationship. When the modulating voltage Vmod of the MOD 1 is increased from V1 to V2, the frequency f of the frequency-modulated wave output from the VCO 2 increases from f1 to f2 in corresponding fashion.

As described above, by varying the output voltage Vmod of the MOD 1 and thereby switching the frequency of

the frequency-modulated wave between the upper region and the lower region within the band, the projection angle of the combined beam pattern can be varied in upward/downward directions.

Figs. 11A and 11B are diagrams showing the relationship between the frequency f of the frequency-modulated wave and the tilt angle θ. As shown in Fig. 11A, when the frequency f of the frequency-modulated wave increases from f1 to f2, the tilt angle θ also increases from θ1 to θ2. Fig. 11B shows how the combined beam pattern varies when the tilt angle θ is varied from θ1 to θ2.

As shown in Fig. 11B, the projection angle of the radar beam pattern can be varied in upward/downward directions without varying the mounting angle of the radar sensor head or the angle of the antenna.

Embodiment 2

Fig. 12 is a diagram showing one configuration example of a two-antenna FM-CW radar according to the present invention. The difference from the configuration shown in Fig. 3 is the inclusion of a phase shifter 10 which is provided between the receiving antenna AR and the mixer 4. Here, the phase shifter may be provided between the transmitting antenna AT and the directional coupler 3.

In the two-antenna radar apparatus shown in Fig. 12, the phase of the radio wave to be transmitted or received is controlled by the phase shifter PS provided on either the transmitting or receiving side, and in this way, the projection angle of the beam pattern can be varied in upward/downward directions while holding the antenna stationary. According to the present invention, an overbridge can be detected by varying the projection angle of the beam pattern in upward/downward directions

while holding the antenna stationary.

Fig. 13 is a diagram showing one configuration example of a single-antenna FM-CW radar according to the present invention. The difference from the configuration shown in Fig. 4 is the inclusion of a phase shifter 10 which is provided between the transmitting/receiving antenna ATR and the transmit-receive switch.

In the single-antenna radar apparatus of Fig. 13 also, by providing the phase shifter PS on the transmitting/receiving antenna ATR, the projection angle of the beam pattern can be varied in upward/downward directions while holding the antenna stationary, and an overbridge can be detected by varying the projection angle of the beam pattern in upward/downward directions while holding the antenna stationary.